BELLCOMM, INC.

SUBJECT: S-IVB/J-2 Engine Restart
Case 330

DATE: May 15, 1967

FROM: A. T. Ackerman

ABSTRACT

The present S-IVB/J-2 restart problem is a result of an inconsistency between the Apollo Program Specification, which indicates translunar injection from the first orbit, requiring a 35 minute restart capability, and the J-2 Engine Model Specification, which requires only a 90 minute restart capability. Thus, the specified engine restart time does not allow for any first orbit and some second orbit injection opportunities.

Data from the flight of AS-203 indicated that S-IVB/J-2 would not even restart at 90 minutes due to the high temperatures in the gas generator exhaust system.

Preliminary AEDC test results conducted since the 203 flight indicated satisfactory restart at 90 minutes by starting the engine with a low oxidizer/fuel mixture ratio, slowing the response of the main oxidizer valve, and by painting the cross-over duct black to change the thermal characteristics.

To obtain a 35 minute restart capability, additional modification would be required both to the stage and engine to provide for cooling the gas generator exhaust system and to overcome the high LH_2 vapor pressure caused by high tank wall temperatures. Initial estimates indicate a 16 month schedule and a cost of \$3-5M to provide a kit for a 35 minute restart capability.

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(NASA-CR-153866) S-IVB/J-2 ENGINE RESTART (Bellcomm, Inc.) 9 p

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MEMORANDUM FOR FILE

I. PROBLEM BACKGROUND

The present S-IVB/J-2 restart problem is a result of an inconsistency between the Apollo Program Specification and the J-2 Engine Model Specification.

The Apollo Program Specification states in paragraph 3.1.1.2.6 "injection into a lunar transfer trajectory shall occur no later than 4.5 hours after earth orbit insertion. The capability shall be provided for injection on either of two successive earth orbits." This connotes injection from the first orbit.

The J-2 Engine Model Specification states in paragraph 3.3.6 "the engine starting system shall provide for one opportunity for restart within a 6 hour period. The elasped time from first engine cutoff to engine restart shall be at least 90 minutes and not more than 6 hours." The 90 minute minimum restart requirement in the engine specification does not allow for any first orbit and some second orbit injection opportunities.

It was pointed out* that in order to obtain all second orbit translunar injection (TLI) opportunities, an 80 minute restart capability would be required while Pacific-only first orbit opportunities would require 35 minutes. This memorandum discusses the changes necessary to satisfy either an 80 or 35 minute restart.

II. DESCRIPTION OF ENGINE START SEQUENCE

The J-2 engine is started by having hydrogen gas from the start bottle initially rotate the fuel and oxidizer turbopumps. This initial rotation pumps fuel and oxidizer into the main chamber and gas generator in which they are ignited. The initial flow of gaseous hydrogen is replaced by the gas generator exhaust to further increase the turbo-pump speeds, and this in turn feeds more propellant to the gas generator as well as to the main chamber. This process called bootstraping, continues until the engine has reached steady state operating conditions.

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*Memorandum for File, "S-IVB Restart Requirements," dated April 4, 1967, by R. L. Wagner

[redacted]

Referring to Figure 1, a somewhat more detailed description of the engine start sequence follows:

1. The Main Fuel Valves (MFV) are opened.

2. High-pressure, gaseous hydrogen (GH_2) is discharged from the Start Tank to start rotation of the 25,000 RPM hydrogen turbine. The flow then divides, part going through the Cross-Over Duct to start rotation of the 8,000 RPM oxidizer turbine; the rest is dumped overboard through the Oxidizer Turbine Bypass Valve.

3. The ratio of fuel to oxidizer turbo-pump speeds is controlled by an orifice in the oxidizer turbine bypass duct.

4. As the turbo-pumps rotate, propellants are pumped into the Gas Generator and the Main Oxidizer Valve (MOV) begins to open.

5. Propellants in the Gas Generator are ignited and the hot exhaust gases now continues to accelerate the turbo-pumps, increasing the flow of propellants into the Gas Generator and into the main chamber where they are also ignited.

6. The turbo-pumps continue to accelerate, pumping more propellants into the Gas Generator and more propellants into the thrust chamber until the engine has reached steady state operation.

III. <u>80 MINUTE RESTART</u>

Data from flight AS-203 showed that the S-IVB/J-2 would be unable to meet its own restart requirement of 90 minutes due to gas generator over temperature. This high temperature is the result of insufficient time for the exhaust system (turbines, cross-over ducts, etc.) to cool down after the first burn. The hot exhaust system adds additional energy to the GH_2 used in spinning up the oxidizer pump, resulting in pump overspeed, excessive LOX flow to the gas generator, excessively high gas generator operating temperatures, and finally degradation of the structural integrity of the gas generator.

To overcome this problem and provide for the 90 minute restart capability, MSFC is planning to incorporate the following modifications into the J-2 engine:

1. Starting the engine with a low mixture ratio (PU valve open).

2. Retiming the Main LOX Valve (slower response).

3. Painting the turbine cross-over duct black.

Testing of these modifications at AEDC has demonstrated satisfactory engine start at 90 minutes. Figure 2 is a plot of the gas generator temperature during starts of some AEDC tests. Curve A shows the temperature of the gas generator with none of the above modifications; the maximum temperature was 2425°F. Curve B shows the effect of starting with the PU valve in its low mixture ratio setting; the maximum temperature was only 2177°F. Curve C shows the additional effect of a slower main oxidizer valve; in this test the maximum temperature was reduced to 2100°F. The painting of the cross-over duct black (high emissivity) should further reduce the maximum gas generator temperature. These tests, scheduled to be completed by July, 1967, in all likelihood will also demonstrate capability for an 80 minute restart.

IV. 35 MINUTE RESTART

To obtain the 35 minute restart capability, the S-IVB/J-2 must be further modified to provide for cooling of the exhaust gas system by supplying purge gas from the stage to the engine. This purge system modification would include plumbing, electrical and control changes to both the engine and stage. Initial estimates indicate a 16 month schedule for these changes at a cost of $3-5M.

There is an additional problem in the stage when trying to reach a 35 minute restart capability. The heated tank walls do not cool sufficiently after the first burn due to the shortened coast time. The hot structure can heat the liquid hydrogen during the second burn, increasing its vapor pressure. This results in lower-than-required Net Positive Suction Head, NPSH, being supplied to the J-2 engine. To overcome the increased vapor pressure of the propellants, higher LH_2 ullage pressures are required, and this in turn might mean structural modifications to the stage. MSFC and Douglas are presently analyzing this problem.

V. CONCLUSIONS

It appears that the 80 minute restart capability will be satisfied by the changes necessary to meet the 90 minute model specification. On the other hand, the 16 month schedule impact of the 35 minute restart capability may preclude its use on early Apollo vehicles. In this case, the $3-5M cost might be applied to the J-2S* engine to provide an essentially unlimited (as to

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*S for simplified.

the time after initial burn) restart capability for use on other programs. In the J-2S engine, the gas generator has been eliminated and hot gases from the main chamber are used to drive both fuel and oxidizer turbo-pumps. Initial pump rotation (to start the bootstrap process) is obtained from a start cartridge.

A. T. Ackerman

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Attachments
Figures 1-2

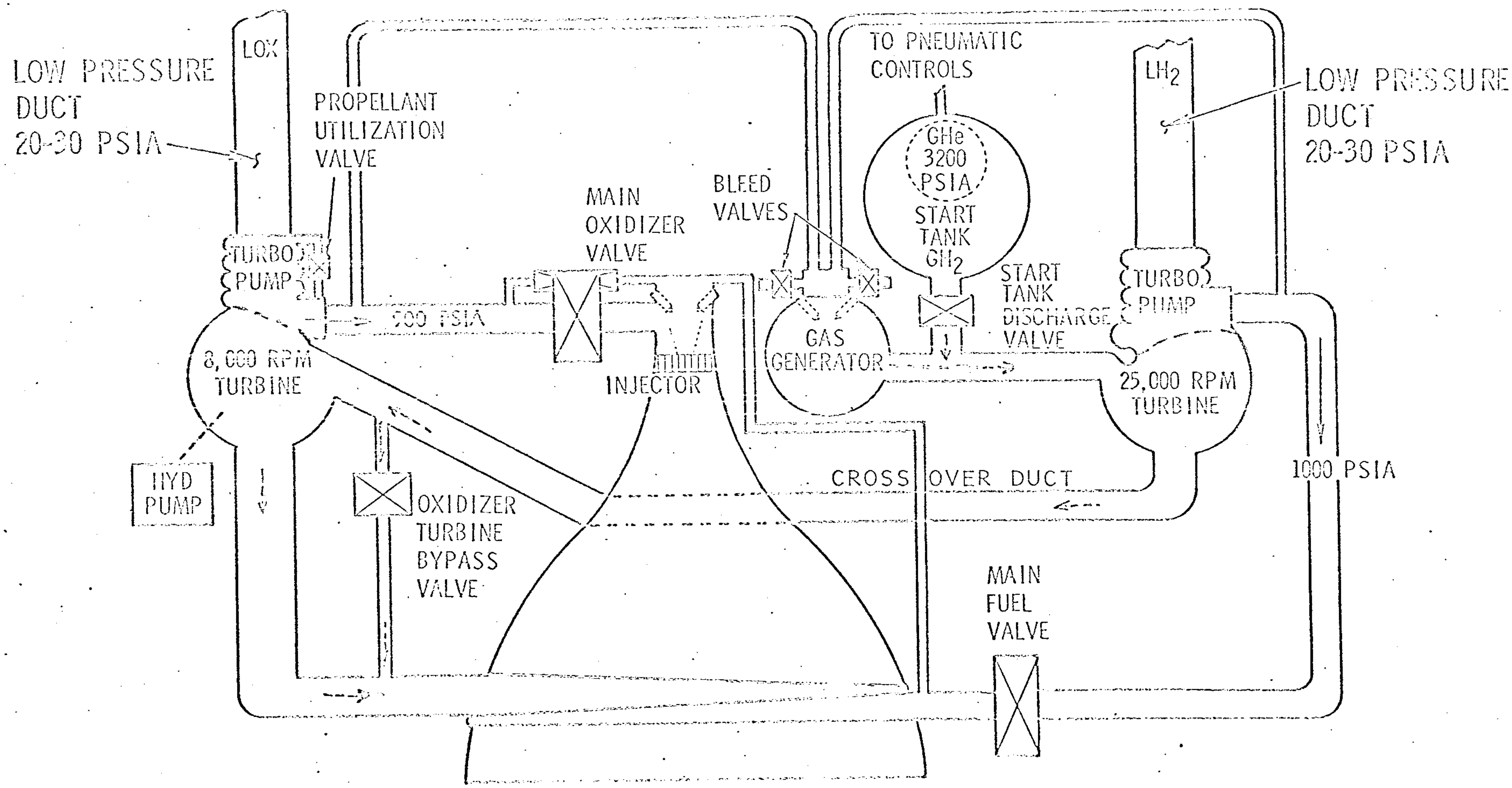


FIGURE I - SIMPLIFIED J-2 ENGINE SYSTEM

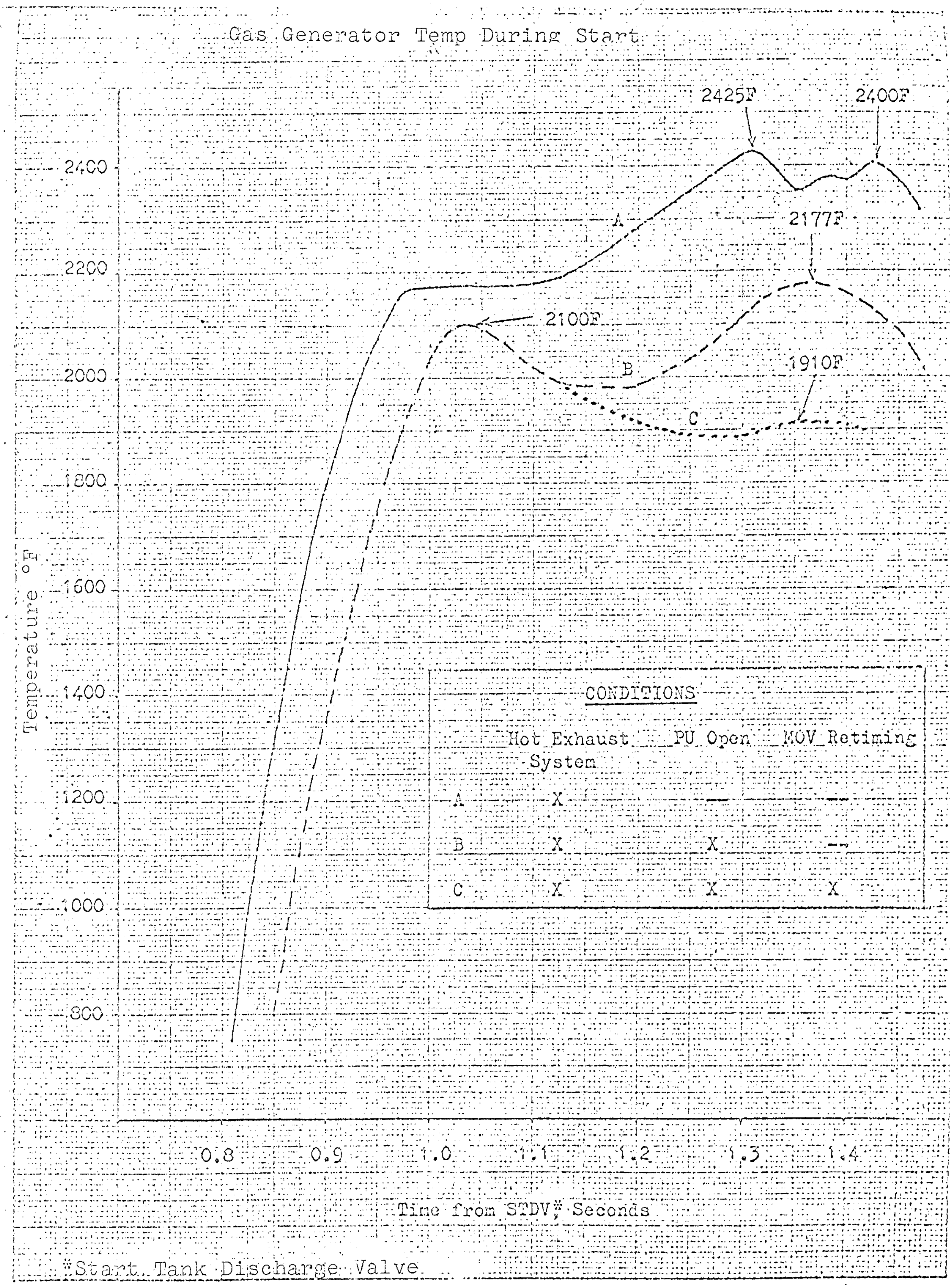
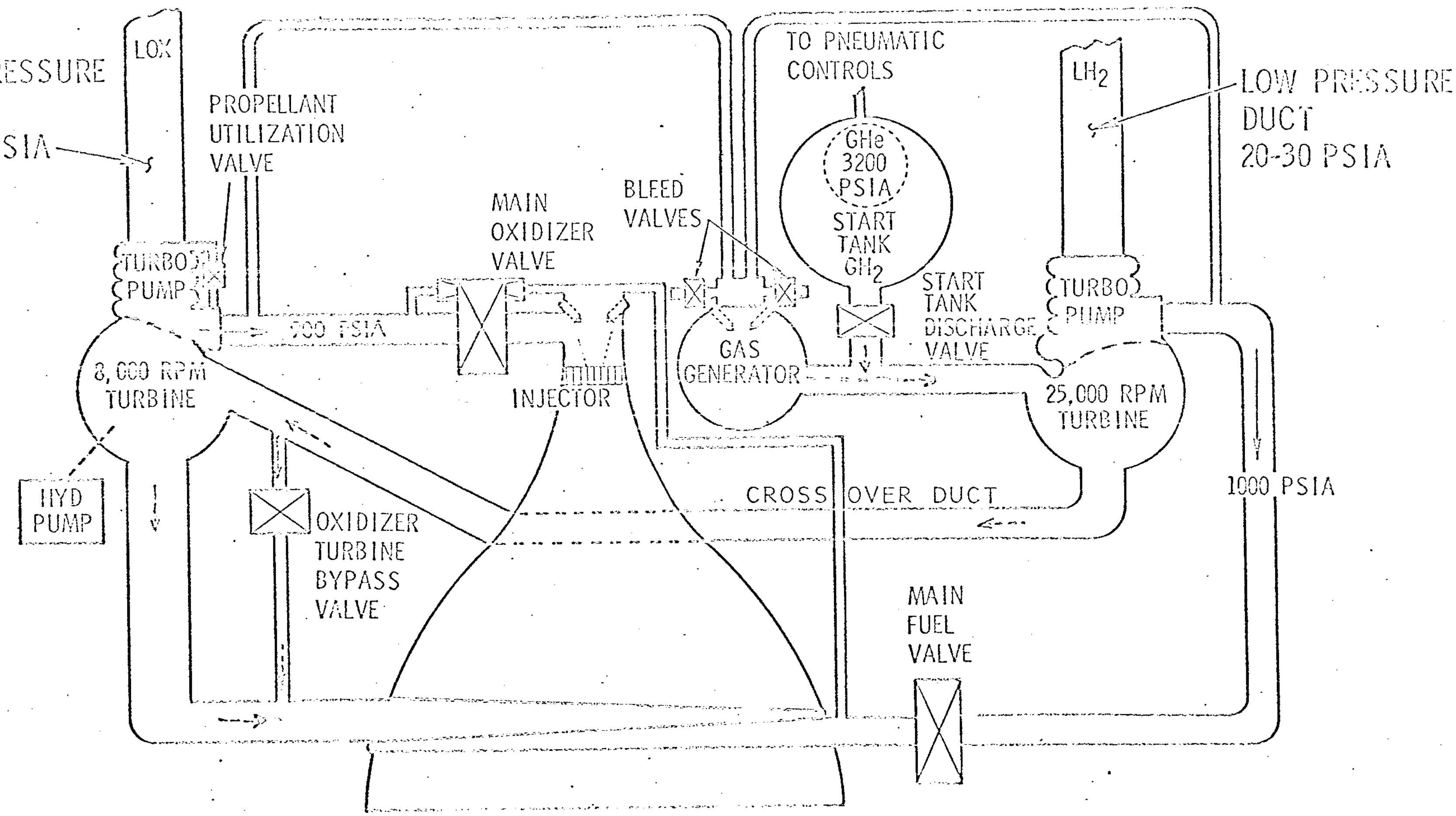

Gas Generator Temp During Start
2425F
2400F
2177F
2100F
1910F
A
B
C
2400
2200
2000
1800
1600
1400
1200
1000
800
Temperature °F
CONDITIONS
Hot Exhaust System
PU Open
MOV Retiming
A X
B X X
C X X X
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Time from STDV,* Seconds
*Start Tank Discharge Valve

Figure 2



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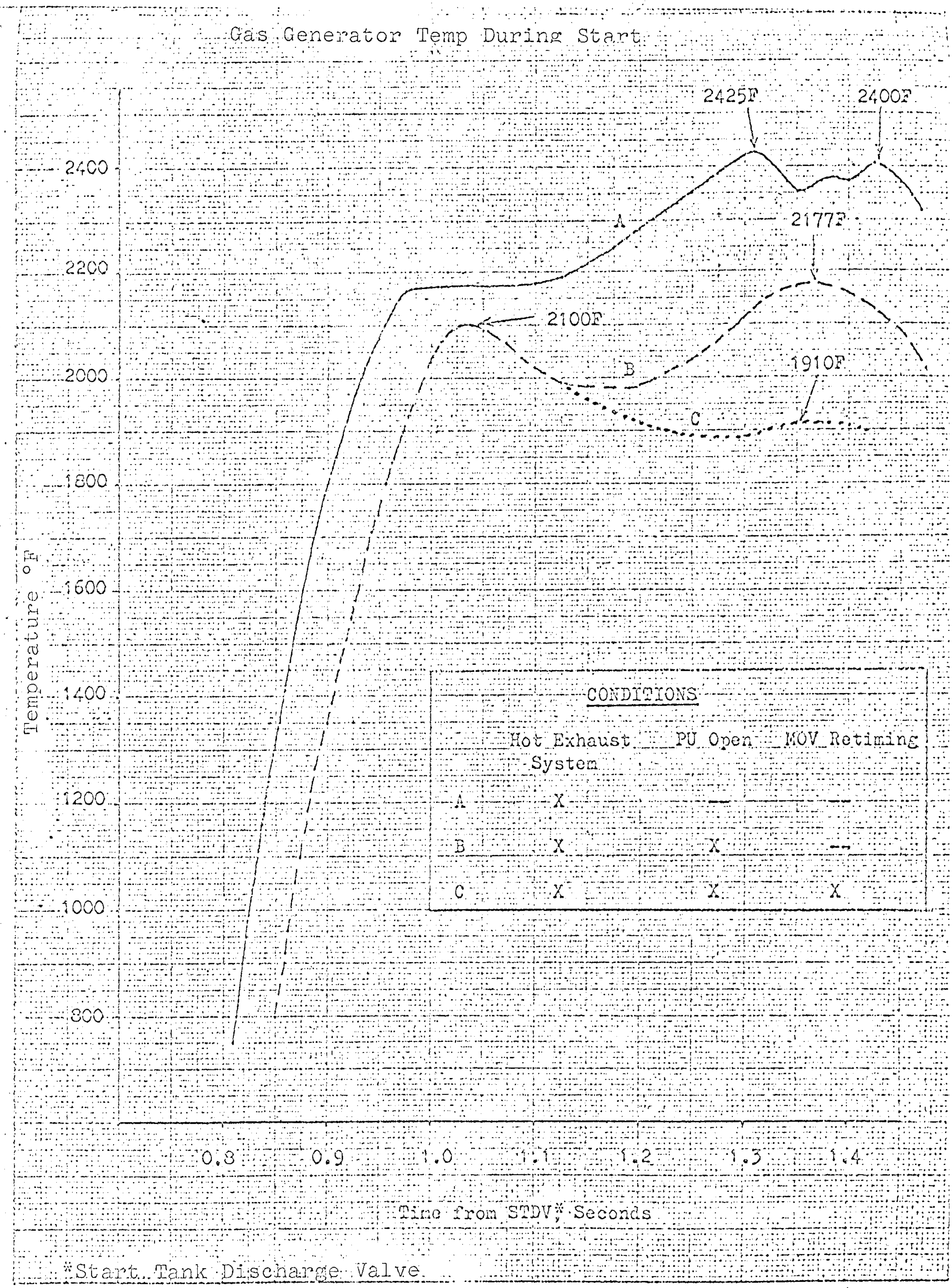

Gas Generator Temp During Start
2425F
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A
B
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Temperature °F
2400
2200
2000
1800
1600
1400
1200
1000
800
CONDITIONS
Hot Exhaust System
PU Open
MOV Retiming
A X
B X X
C X X X
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Time from STDV,* Seconds
*Start Tank Discharge Valve

Figure 2

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